EVALUATION OF THE OPERATIONAL DIAGNOSTIC CLOUD FORECAST MODEL

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INTRODUCTION

The Air Force Weather Agency (AFWA) is dedicated to providing cloud cover forecasts for military mission planners involved in flight operations including ground surveillance, in-flight refueling, close air support, and weapon selection for surgical air strikes. The current models used to produce these forecasts have been unable to deliver accurate predictions beyond 12 hours. At the beginning of 2003, AFWA introduced the Diagnostic Cloud Forecast (DCF) model to generate longer-range accurate regional cloud forecasts. Originally developed by the Air Force Research Laboratory (AFRL) (Norquist, 1997; Norquist, 1999; Norquist et al., 2002), DCF statistically relates the Cloud Depiction and Forecast System II (CDFSII) World Wide Merged Cloud Analysis (WWMCA) with regional MM5 theater forecasts. DCF is capable of producing forecasts on either a 45-km resolution grid out to 72 hours or a 15-km resolution grid to 48 hours, depending upon the configuration of MM5.

DCF is a complimentary cloud forecasting model to the AFWA Advect Cloud (ADVCLD) model. ADVCLD uses trajectories computed from the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) three-dimensional wind fields, along with temperature, dew point, and pressure, to advect existing clouds and generate/dissipate clouds based on resolved ascent/descent (Kopp et al., 1997). This technique provides a very efficient method for producing accurate cloud forecasts out to 12 – 18 hours; however, the lack of detailed cloud physics within the model contributes to significant degradations beyond 18 hours. For example, ADVCLD does not predict the formation of convective clouds or orographically forced clouds.

DCF uses a statistical algorithm to analyze 102 different variables (predictands) (Norquist, 1999) from MM5 forecasts and pairs them with cloud-filled pixels in the WWMCA. DCF gathers WWMCA information on cloud amount, top and base heights, thickness, type, and pixel age. Only those pixels with ages less than two hours are used for statistical comparison. The cloud/predictand pairs are gathered for a 10-day period after which a forward, stepwise regression statistical significance test is used to reduce the 102 predictors into a more manageable set of 20. These values are reduced even further using a multiple discriminate analysis to determine which of the pairings best estimate cloudiness. The final values, termed coefficients, are built on a daily basis from a sliding 10-day set of cloud/predictand pairings and provide a real-time adaptive statistical database. Each MM5 theater has a separate statistical database, which allows separate meteorological, geographical, or temporal parameters to become statistically significant depending on theater geography, weather patterns, and climatology. Assuming the coefficients are statistically stationary, cloud forecasts are diagnosed from current MM5 forecasts.

DCF provides increased cloud forecast accuracy over ADVCLD and MM5 because it does not rely solely on microphysical parameterizations to produce clouds. Parameterizations, such as those in MM5, use vorticity, temperature, moisture, vertical motion, etc. to produce cloud liquid water and ice content. However, it is very difficult to achieve highly accurate cloud forecasts with mesoscale model parameterization schemes using large grid sizes and temporal scales since cloud development/decay is very subscale in nature. The statistical approach aids parameterized forecasts with the statistical fortitude to more accurately forecast cloud.

Unlike raw MM5 clouds, output from DCF can be tailored to provide mission essential parameters. MM5 provides cloud top and base heights at each pixel based on a yes/no cloud flag; however, it cannot output cloud amounts for more than one level or total cloud amount necessary for cloud-free line-of-sight products and mission targeting. DCF diagnoses categorical values for cloud amounts in 20% increments for up to 5 layers plus total cloud amount, cloud base height, cloud thickness (which is converted to cloud top height using diagnosed base heights), and a categorical cloud type. The output from DCF has been tailored to meet specific mission requirements including reconnaissance, refueling, close air support, and targeting operations which require total and layer cloud amounts, cloud base heights, and cloud top height forecasts.

OBJECTIVE PERFORMANCE ANALYSIS

AFWA objectively verifies DCF daily and produces monthly statistics on the DCF performance as compared to the WWMCA for total cloud amount. AFWA is developing new statistical methods to objectively verify cloud top height diagnoses. The current objective verification uses root mean square error (RMSE) and bias calculations to determine the numerical performance of DCF over monthly periods. Statistical charts for the Southwest Asian (SWA) theater are depicted in Figure 1. The chart illustrates differences between ADVCLD and DCF, with RMSE values increasing during the first 12 hours for ADVCLD more rapidly than for DCF. The largest difference between DCF and ADVCLD is found in the bias, with ADVCLD having a large positive bias and DCF having a bias slightly above zero.

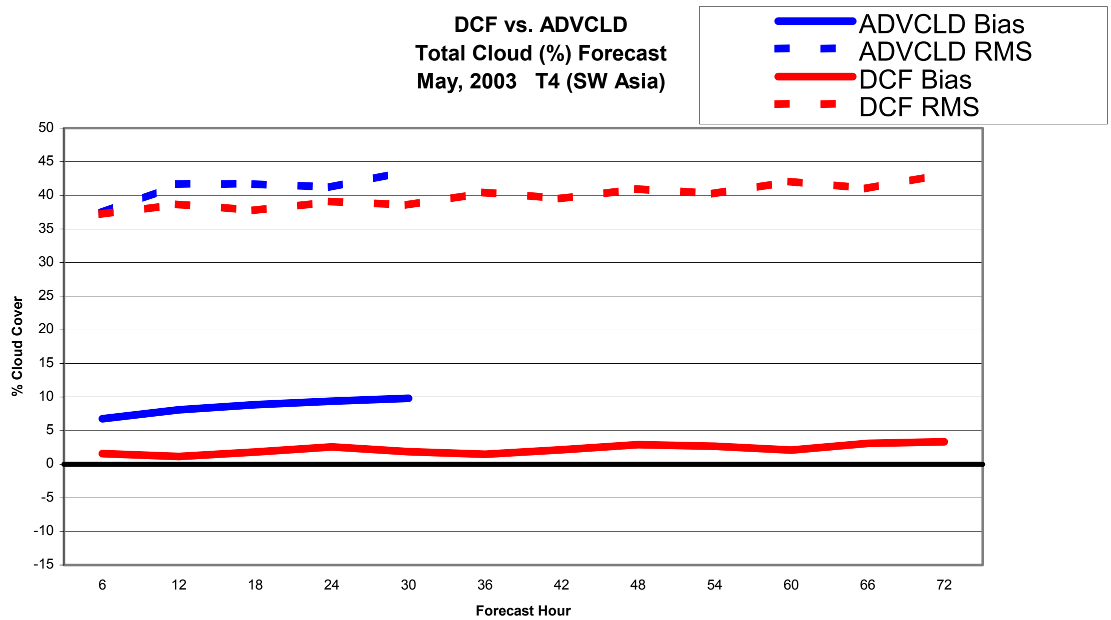

Figure 1. RMSE and bias values for DCF and ADVCLD over SWA for May 2003.

SUBJECTIVE PERFORMANCE ANALYSIS

Three individual cases were analyzed to compare DCF, MM5, and ADVCLD for two separate theaters. The first evaluation at 1200 UTC on 12 May 2003 compared each of the three cloud forecasting schemes (MM5, ADVCLD, and DCF) over SWA against the CDSFII WWMCA analysis and infrared satellite imagery from Meteosat-5 (ME5). Two additional cases were used to evaluate cloud forecasting over SWA. The DCF and ADVCLD for 1800 UTC on 12 May 2003 were compared with the corresponding WWMCA and ME5 images, while the DCF and MM5 for 1800 UTC on 03 June 2003 forecasts were also evaluated. The separate cases for SWA were necessary due to data availability issues. Comparisons were made for each of the three models during the first 30 hours of the forecast. Beyond 30 hours, only the MM5 and DCF were available for comparison. The WWMCA was used as ground truth for the verification since both DCF and ADVCLD are initialized from the CDFSII analysis. Finally, the forecasts were compared against ME5 images to provide a final truth to compensate for over or under analysis of clouds within the WWMCA.

SWA was chosen not only because of recent operational interest, but also for the unique weather elements present during the time of the study. The southern portion of the window is unique due to the northward advance of the inter-tropical convergence zone (ITCZ). The northern portion of the window is within the predominant westerlies and deserts cover much of the central portion of the theater. The unique weather and geographic character provide an interesting challenge for DCF. While the Bay of Bengal is not included in the SWA MM5 and DCF windows, a tropical cyclone (TC 01B) over the far western Bay of Bengal affected cloud cover over the Arabian Sea and southwestern India in the southeast corner of the theater. A couple of synoptic disturbances moved from west to east over the northern and northwestern portions of SWA during this case study. The central section of the theater was dominated by very little cloudiness most likely due to the subtropical high pressure extending westward over northern Africa (Sahara Desert).

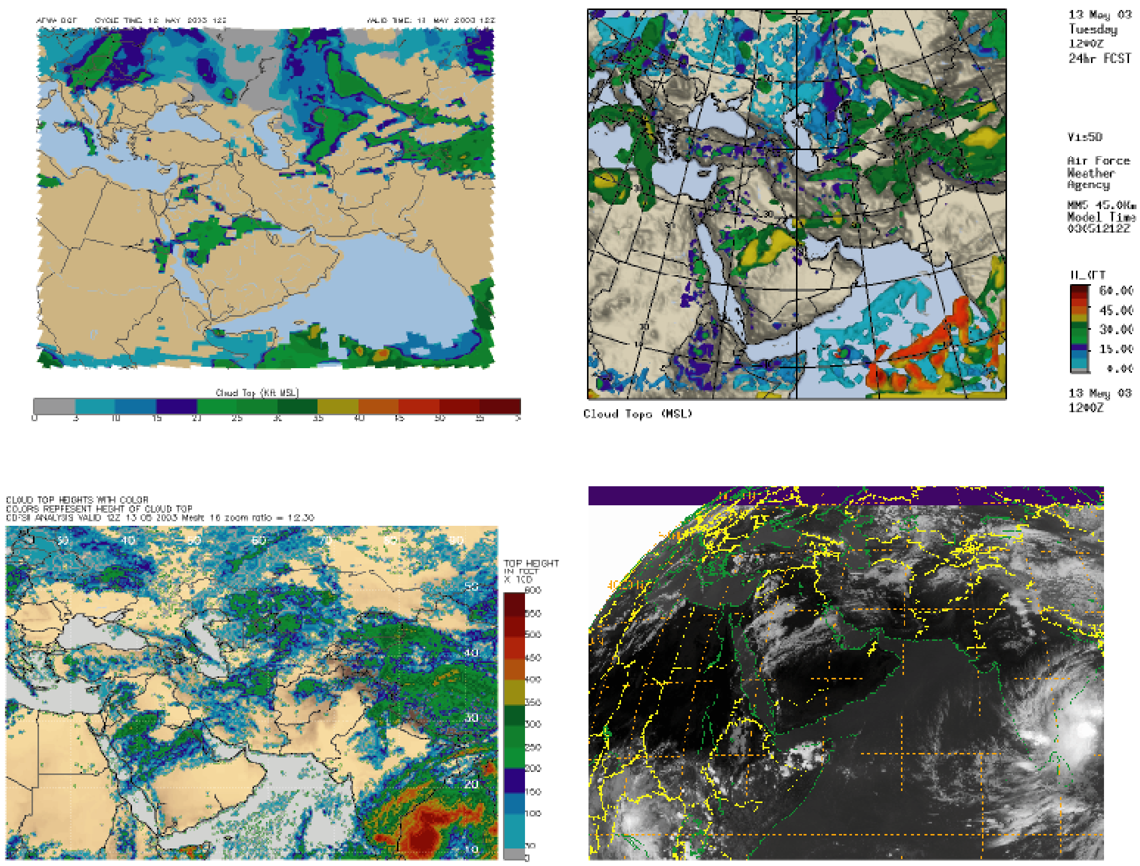

Figure 2. DCF (upper left) and MM5 (upper right) 24-hour cloud height forecasts for SWA valid at 1200 UTC on 13 May 2003, with the WWMCA cloud height product (lower left) and ME5 satellite image (lower right) valid at the same time. Analysis of these images illustrates the over forecasting of high clouds evident in MM5, while the DCF cloud height forecast more closely resembles the satellite image and analysis.

The strengths and weaknesses of each of the three cloud forecasting techniques were highlighted during this case study. In the first period, DCF slightly under forecast cloud amount over land during the early forecast hours with the accuracy increasing beyond 18 to 24 hours. DCF overanalyzed cloud amount over the ITCZ where larger cloud amounts are noted along the southern edge of the DCF forecast area with lesser cloud amounts noted in the analysis. DCF provided increased accuracy of both cloud placement and cloud height forecasting during the entire time period of this case study. Figure 2 illustrates some of the differences between the DCF and MM5 forecasts.

Differences between the cloud top height forecasts from MM5 and DCF, as compared to the WWMCA cloud top height analysis and satellite imagery, are readily apparent. DCF more accurately forecast the highest cloud tops over the Arabian Sea, while MM5 continued to over-forecast high clouds in that region. This difference occurred frequently throughout the study. DCF also accurately diagnosed cloud top heights over Kazakhstan and eastern Europe. The DCF cloud top height product was structurally similar to the analysis at nearly every time step throughout the forecast period.

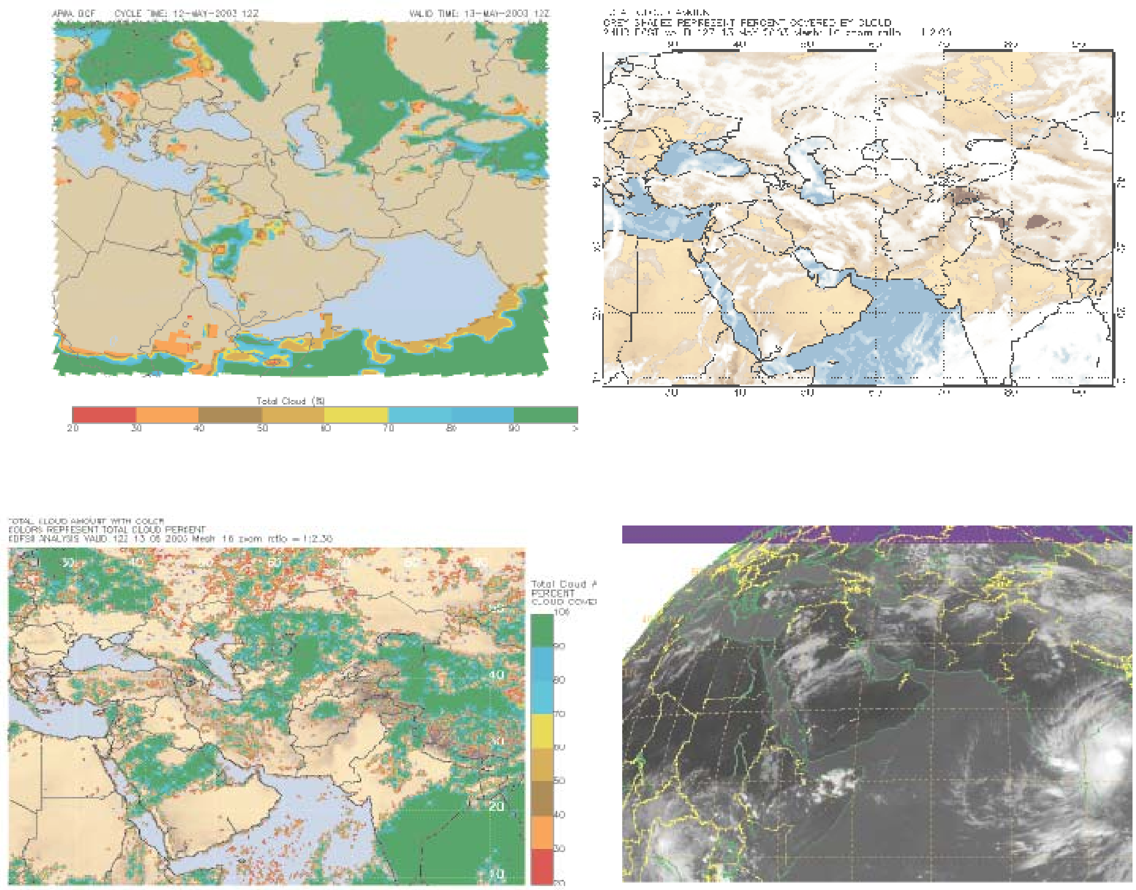

Figure 3. DCF (upper left) and ADVCLD (upper right) 24-hour forecasts for SWA valid at 1800 UTC on 13 May 2003, with the WWMCA total cloud amount image (lower left) and ME5 satellite image (lower right) valid at the same time. The ADVCLD forecast saturates the window with clouds during the later forecast hours as evident by the high amount of clouds in the northern half of the window.

During the first 12 hours of the forecast period, ADVCLD provided the highest accuracy, with correct cloud amounts and exact placement of features; however, DCF outperformed both MM5 and ADVCLD in subjective analysis during the post 18-hour forecast times. DCF accurately forecast the placement of synoptic cloud features throughout most of the 72-hour forecast. Figure 3 illustrates a 24-hour forecast from DCF and ADVCLD. ADVCLD contained an extremely high amount of cloud covering much of the theater, while DCF contained cloud structures and amounts much closer to that observed in the ME5 satellite image and the WWMCA.

Figure 4 compares the DCF 66-hour total cloud amount forecast with the corresponding WWMCA total cloud amount analysis and ME5 satellite image. The structure of the clouds in the forecast bears striking resemblance to the features noted in the analysis and ME5 imagery. The WWMCA cloud amount analysis contains a large amount of low percentage cloud that may not be apparent in the ME5 imagery. DCF appears to be largely under forecasting the low percentage cloud when compared to the WWMCA; however, it appears to contain much higher skill when analyzed against the ME5 imagery. This 66-hour forecast is an excellent example of the skill associated with the long-range capabilities of DCF.

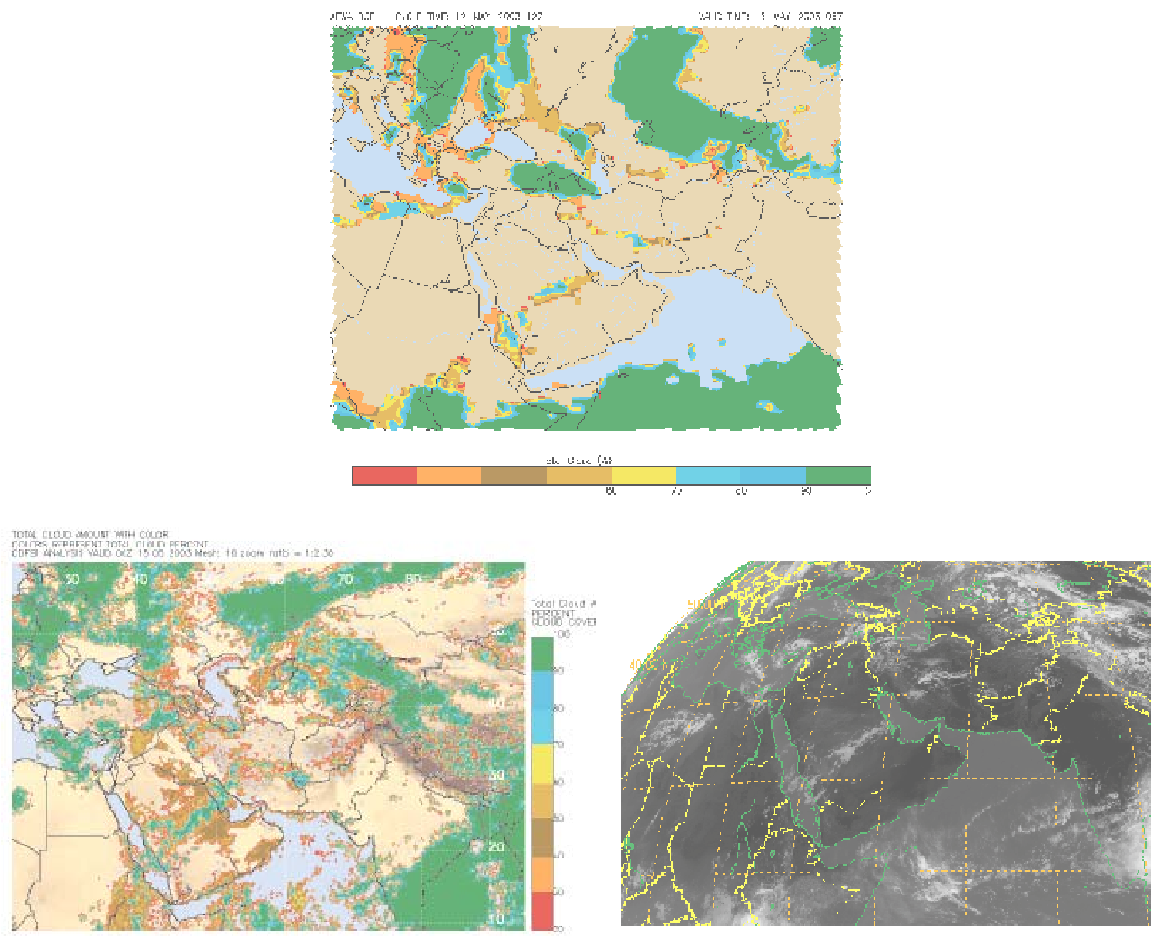

Figure 4. DCF (top) 66-hour total cloud amount forecast for SWA valid at 0600 UTC on 15 May 2003, and WWMCA total cloud amount image (lower left) with ME5 satellite image (lower right). In this case, DCF produced a good forecast with the overall placement of features, including the thin strip of cloud through Saudi Arabia, clouds in southeast Kazakhastan, as well as those over the eastern European countries.

DCF was again compared to ADVCLD at 1800 UTC on 12 May 2003 over the Western Pacific/Eastern Asian (WPAC) theater. The results for this test were comparable to those seen in SWA. ADVCLD provided accurate forecasts during the first 12 to 18 hours of the forecast with features in the forecast identifiable in the analysis. Beyond 18 hours, ADVCLD began to saturate the theater with a large quantity of cloud-filled pixels. DCF more closely resembled the WWMCA and satellite imagery throughout the remainder of the forecast period.

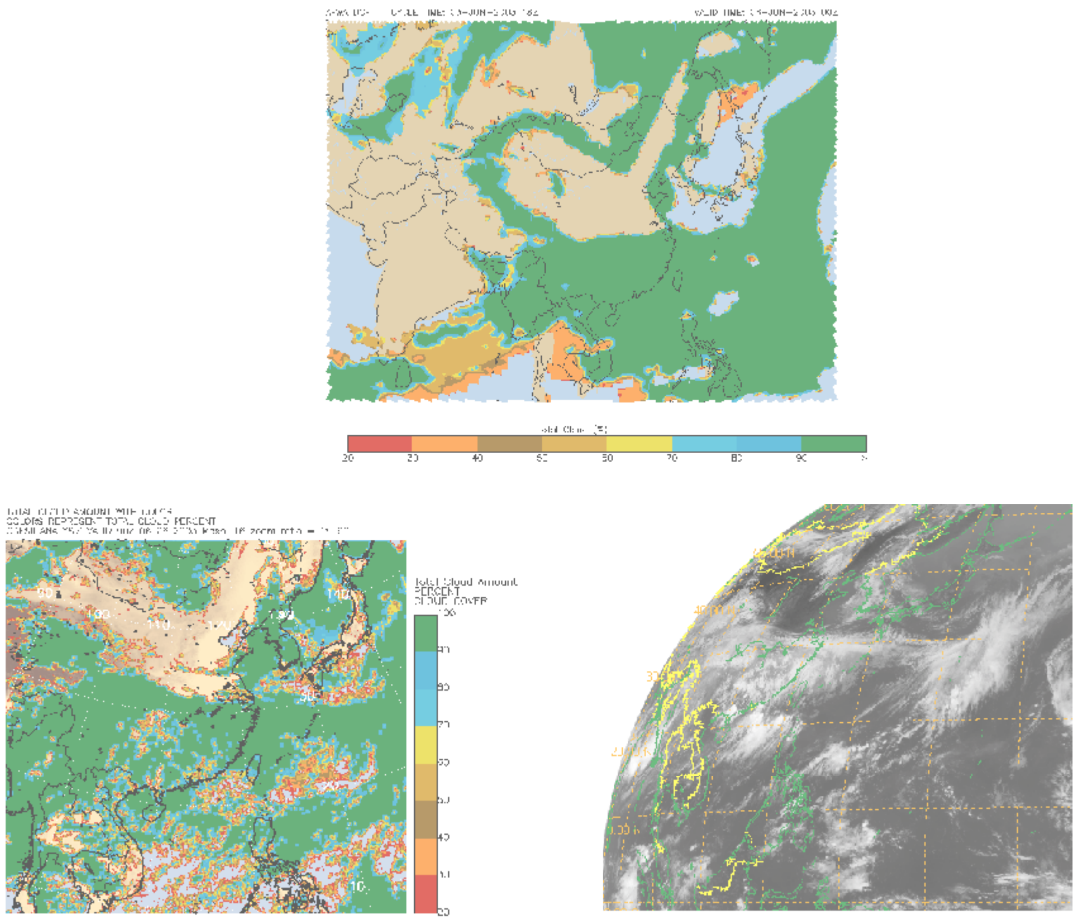

Figure 5. DCF (top) 54-hour total cloud amount forecast for WPAC valid at 0600 UTC on 6 June 2003, and WWMCA total cloud amount image (lower left), with GOES-9 IR satellite image (lower right). The DCF forecast has good placement of clouds and clear areas. Note the clear area in southwest Mongolia and northern China in both the analysis and forecast.

Tropical cyclone (TC-01B) affected the western sections of the Bay of Bengal during this case study and was included within WPAC. DCF forecasts accurately portrayed the location and cloud top heights associated with the tropical cyclone. Conversely, there were some differences in location of the cloud shield edge in some forecast hours, most notably along the northern sections of the Bay of Bengal. DCF also had difficulty maintaining the organization and appearance of the highest cloud tops during parts of the forecast; however, this shortcoming can be related back to the mesoscale forecast of organization and intensity of the system by MM5. Previous forecast cycles of MM5 included a significant amount of high clouds greater than 50,000 ft, while the DCF cloud height forecasts were more in line with the observed heights in the WWMCA.

Finally, DCF was compared to the 1800 UTC run of MM5 over WPAC on 03 June 2003. In this case, DCF performed well versus WWMCA. MM5 incorrectly forecast the cloud heights and amount of high clouds over China and the northern Philippines. The ITCZ was located over the northern Philippines during this time period. DCF more accurately forecast the amount of high clouds associated with the ITCZ; however, it slightly under forecast the height of the clouds over eastern China. The intensity of the under forecasting of cloud heights over eastern China was not as severe as MM5 over saturated regions with large amounts of high clouds. DCF diagnosed cloud amounts well and nearly matched the WWMCA visualizations at all forecast periods in subjective analyses, including locations of clear areas and edges of the 100% cloud-covered areas (Figure 5). Throughout the time period, there were slight differences between the location of the cloud edge in the analysis and the location of the cloud edge in the forecast. The differences appeared uniform throughout the extended period of the forecast between 30 and 72 hours.

Summary and Conclusions

DCF was compared to both MM5 and ADVCLD to find strengths, weaknesses, and differences between the three model cloud forecasts and provide a summary of the operational benefits DCF provides over the other cloud forecast models. ADVCLD proved highly accurate in placement of features and forecasting cloud amount during the first 12 to 18 hours of the forecast; while beyond 18 hours, the accuracy of ADVCLD deteriorated rapidly. ADVCLD provided little operational benefit by the end of its forecast, with the forecast nearly saturated with cloud. On the contrary, DCF provided a very valuable forecast in the period beyond the 12-hour forecast. Even at 54 – 60 hours, the cloud top heights and total cloud amounts produced by DCF very closely resembled features in the WWMCA and satellite imagery. The added cloud forecasting skill DCF provides can be a great benefit to military planners requiring accurate forecasts of total and layer cloud amounts and layer cloud height information for flight operations, targeting support, reconnaissance, and refueling missions. DCF provides a more accurate regional look at future cloud conditions to longer ranges than previously available.

DCF accurately forecast synoptic scale or large organized mesoscale cloud features in the three case studies analyzed. It did not do a very good job forecasting subscale phenomena occurring over larger regions, nor did it detect broad regions of scattered clouds appearing over land in Iran and over the Arabian Sea. The regions of cloudiness DCF had the most problems with were those scattered regions of cloudiness not associated with an organized system. Since the theaters analyzed were using the 45 km resolution MM5 grid, regions of subscale forcing not forecast well by MM5 would also not be forecast well by the DCF, due to the statistical significance needed to provide a relationship. DCF also slightly over forecast the amount of clouds associated with the ITCZ in SWA.

DCF forecast accuracy depends on the relationships created between MM5 and the WWMCA, where horizontal resolution is a large factor. The best correlations will result where MM5 is either performing well or poorly on a consistent basis. Therefore, if a significant amount of clouds associated with a specific synoptic or larger mesoscale pattern equal to or greater than the grid size can be paired in the sampling to become statistically significant, DCF will provide accurate forecasts for these future cases. If there are only a couple of types of cloud/predictand pairings in a given theater or the pattern is subscale in nature to the MM5 forecast grid used, DCF will not be very accurate in its forecast of such phenomena. This conclusion raises some questions that will need to be answered in further development of DCF including what affect an increased grid resolution would have on the accuracy of the forecast.

Currently, the statistical sampling of cloud/predictand pairings is very large due to the vast amount of timely data available in the WWMCA. AFRL initially developed DCF to sample from the Real Time Nephanalysis (RTNeph), which contained only DMSP polar orbiting satellite data. The WWMCA consists of a global network of geostationary satellites, including the NOAA GOES-9, GOES-10, and GOES-12 satellites; and the European Meteosat-5 and Meteosat-7 satellites, in addition to the DMSP polar orbiter satellites. The geostationary satellites have added a tremendous amount of timely data to the each hourly analysis. Due to this larger dataset, the statistical sampling possible through DCF has increased dramatically, thus slowing the coefficient build processing. Additionally, CDFSII will soon be using data from the NOAA polar orbiting satellites interjecting even more timely data into the WWMCA. Efforts are underway to decrease the amount of sampling needed, while maintaining forecast accuracy. This is possible by either reducing the pixel age necessary to determine if it is timely or reducing the amount of data used in the sampling. Operational DCF uses ¼ of the timely pixels from the analysis. Reducing the amount further by ½ of the current value may be more cost effective.

Additional testing will assess the operational benefit of higher resolution DCF theater forecasts. Operationally, DCF is only configured to provide forecasts for six theaters with 45-km MM5 domains. Recently, subjective and objective verification of higher resolution 15-km SWA DCF output suggests a significant increase in forecast accuracy. Additional tests are being performed to determine the operational benefit versus cost.

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